

Multi-criteria model for the development of industrial logistics

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Abstract. Development of the industrial manufacturing logistics is associated with the need to solve many problems that affect the main technological units, internal and external transportation, as well as the industrial enterprise management system. The effectiveness of the solution of each of these tasks separately is traditionally evaluated by criteria, which, as a rule, conflict with the criteria of the effectiveness of other tasks and may even contradict the strategic goals of the organization. Modern logistics solutions are based on the achievement of a global economic criterion. However, the practical implementation of such general decisions is limited by the complexity of forming concrete actions based on them. In addition, traditional logistics solutions do not adequately meet the requirements of the concept of sustainable development, as they are poorly oriented towards environmental and social criteria. The developed multi-criteria model is a combination of alternative logistics solutions and criteria for their evaluation. The procedure for assessment and choosing the best combination of logistic decisions is based on a combination of multi-criteria decision-making methods. Application the developed model will reduce the costs of designing and implementing logistics solutions, as well as ensure the achievement of the sustainable development goals of an industrial enterprise.

1. Introduction

The goals and functions of industrial logistics (IL) are studied in enough detail in the scientific literature [1] and are implemented in practice [2]. Material flows of resources and products, waste, reverse flows, as well as service flows, information and financial flows are the objects of IL management. One of the main tasks of industrial logistics is to coordinate the industrial cycles of various departments of the enterprise for the conversion of raw material flows into finished product flows of the required quality. Modern IL management systems are based on the operational production management method MRP II (Manufacturing Resource Planning) [3]. The practical implementation of the MRP II technique is provided by ERP (Enterprise Resource Planning) software [4].

There is a decrease in the effectiveness of long-term planning and an increase in the importance of operational decisions on adapting enterprises to changing external conditions under the conditions of increasing volatility of the world economic system, regional markets, and a change in technological patterns [5].

A variety of logistics solutions have been developed and are being put into practice. They are mainly aimed at changing the parameters of logistics flows at the levels of current and operational planning. The following solutions were most widely used: inventory management at different stages of



the production cycle [6]; coordination of volumes of internal [7] and external transportation of the enterprise [8] with production plans; management of parameters (volumes, routes) of in-plant material flows [7]; coordination of the duration of production cycles of technological units of the enterprise by regulating the intensity of in-plant material flows [1]; automation of warehouse operations [9]. In [10], a universal system for managing logistics flows in supply chains, aimed at achieving sustainable development goals, was proposed.

Sustainable changes in the parameters of external and internal material flows of an industrial enterprise require coordinated adjustments to the structure and organization of the functioning of the production logistics system (LS). However, in practice, such adjustments in most cases are not considered as logistics solutions. Moreover, the development of appropriate solutions is not a function of production logistics and logistics management. In other words, reconstructive and organizational measures are carried out without a systematic analysis of the dynamics of internal and external material flows of the enterprise. For example, the decision to reconstruct industrial railway stations, as a rule, is made only in case of significant and long-term changes in volumes and/or structure of processed cargo flows [11].

Decisions on the operational change of the technology of production units are less common in IL. Logistic operational management provides, as a rule, sequence management of orders (production plans), as well as planning and control of workload of production units. Adjusting the duration of technological processes by changing the parameters of technological processes of the main production is usually strictly limited [12]. In such conditions, industrial transport can carry out a flexible change in the parameters of material flows through the implementation of various solutions to change the technology of its work. For example, studies [11, 13, 14] provide a description of the so-called flexible technology of industrial railway transport. This technology provides operational management capacity of the transport infrastructure, depending on changes in the intensity and structure of internal cargo flows.

Most researchers in the field of IL [1] consider the material flows and structural units of the enterprise, ensuring their processing and promotion, as objects of study. Until now, there has not been an idea of IL as a system for managing all the logistics flows of an enterprise in relation to each other, as well as with the structure and organization of the functioning of the LS. Obviously, the main reason for this situation is the high complexity of the task of creating Integrated Industrial Logistics. The difficulty lies in the presence of many conflicting criteria and alternative solutions. Currently, there is an increase in the number of criteria and alternatives, associated with the need for enterprises to achieve sustainable development goals [10, 15].

Currently, the scientific direction in Multiple-criteria decision-making (MCDM) is actively developing [16, 17]. These models and methods differ mainly in the complexity and accuracy of implementation, which depend on the number of criteria and alternatives. To compensate for the shortcomings of a multicriteria model, a combination of different models is used [9, 18].

Another promising method for studying complex systems is simulation modeling. Nowadays, the creation of models for the study of logistics systems at various levels of generalization is carried out using a variety of software tools. For example, the AnyLogic simulation software platform [19] allows, within the framework of one model, to study processes at the level of making and implementing operational, tactical and strategic decisions, as well as to model the dynamics of the socio-economic environment. For this, agent, discrete-event (process) and system-dynamic approaches are used, respectively.

This study is motivated by the problem of the formation of Integrated Industrial Logistics, which provides systematic management of all the logistics flows of an industrial enterprise in conjunction with the structure of the LS, its functions and goals in conditions of high dynamics of the socio-economic environment.

The rest of the article is organized as follows. Section 2 contains a formalized description of the structure and functions of the LS using the AnyLogic simulation platform. Section 3 discusses the developed multi-criteria model for the development of IL. A system of criteria and alternatives for a multicriteria model and a flow chart of model implementation are presented. In Section 4 conclusions are discussed.

2. Formalization of the industrial logistics system

A description of the structure and functions of the industrial logistics system is proposed to be carried out using AnyLogic simulation software.

Agent and discrete-event approaches are used to describe the LS at the level of operational logistics management. The following assumptions are made:

- The agent is an element of the logistic flow. Each element is characterized by a certain qualitative property and has a quantitative value (Figure 1, c).
- Four types of logistic flows were determined depending on the quality properties of the flow elements and the features of calculating the quantitative characteristics: the material flow describes the unit volumes of raw materials, components, etc., which change their quality during the production process, passing into finished product and waste streams; service flow – work performed on processing and promotion of the remaining logistics flows, the quantitative characteristic of the service flow element corresponds to the volume of work performed or the number of resources required to perform one technological operation with the material flow element; financial flow – the costs necessary for processing and promoting the rest of the logistics flows, the quantitative characteristic of the element of the financial flow – the amount of costs for performing one technological operation with the element of the remaining logistics flows; information flow – messages circulating in the production logistics management system, the quantitative characteristic of the information flow element determines the amount of information in the message about any event and corresponds to the probability of this event.
- Logistic flow is a combination of several flow elements. Logistic flow is characterized by a route – a sequence of elements of the logistics system through which the stream passes when moving along the logistics chain or LS.
- The element of the logistic system (logistic element) describes the structural unit of the technological chain and the enterprise management system (Figure 1, a). The logistic element performs the following functions: flow delay for the duration of the technological operation; stock holding in case the logistics element is occupied by processing of the previous flow element (Figure 1, b); changing the structure of the logistic flow by combining or disconnecting the flow elements; change in the quality properties of flow elements.
- Each logistic element uses the remaining logistic flows as resources (Figure 1, b, d).
- The structure of the LS is a combination of logistics elements and the relationships between them (Figure 1, e).
- Relations between the structural elements of the LS are described by the routes of logistics flows.

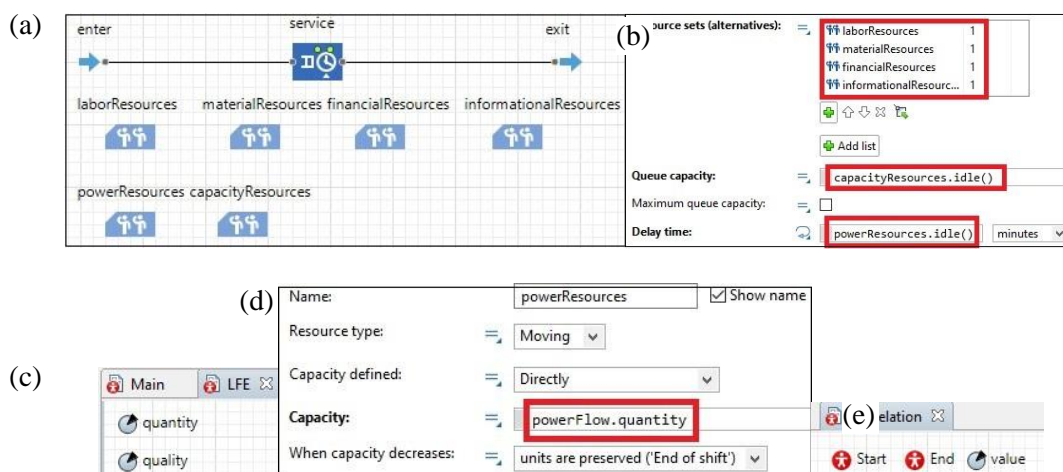


Figure 1. Internal environment of the simulation model's main agents.

The movement and processing of logistics flows of each type is provided by the corresponding logistics subsystem. The interaction of flows is carried out in the internal environment of each agent –

a logistic element. For example, the movement of the main material flow (raw materials, semi-finished products) requires certain resources (Figure 1). The receipt of these resources in the logistic element is carried out as a result of the movement of resource flows through the logistic elements of a logistic subsystem. Logistic flows are exchanged in an agent simulation model using a message passing mechanism between elements. The LS structure is described by a non-planar complete undirected graph.

The presented formalized description of the industrial logistics system in terms of a simulation model allows to unify various technological processes, as well as the functioning of the enterprise management system.

3. The choice of a multi-criteria model for the development of industrial logistics

The choice of a multicriteria model or their combination, as a rule, is determined by the composition of alternatives and criteria for their assessment. The developed multi-criteria model includes L_k , $k = 0, 1, \dots, 6$ hierarchical levels:

- L_0 – industrial logistics development strategy.
- L_1 – sustainability criteria for the IL, the achievement of which ensures the safe, efficient and environmentally friendly functioning of the enterprise (economic, social, environmental) [10].
- L_2 – alternatives for achieving sustainable development goals as a result of organizational changes (products, markets, resources, technologies, social strategies, emissions, waste, reverse logistics [20]).
- L_3 – optimization criteria for the parameters of logistics flows (unevenness, regularity, variability, stability, rhythm) [10].
- L_4 – solutions for optimizing the parameters of logistics flows (element size, structure).
- L_5 – selection criteria for decisions on changing the design of the industrial logistics system (productivity).
- L_6 – solutions for changing the design of the industrial logistics system (power, capacity, number of LS elements, relationships between LS elements).

A feature of the developed multicriteria model is the need to combine decision-making methods at different levels of the hierarchy. A choice from a fixed number of alternatives is made at levels L_1 and L_2 . The alternatives here are the development strategies of various logistics subsystems to achieve several sustainable development goals. It is rational to use the TOPSIS method (The Technique for Order of Preference by Similarity to Ideal Solution) [21] to solve the model at this level. This is due to the potentially large number of alternative strategies that can be formed at the L_2 level.

At levels L_3 – L_6 of the hierarchy, the adoption of Multi-objective decisions (MODM) [22]. In other words, for each logistic flow and each logistic element the optimal parameter values are calculated, which should ensure the achievement of the criteria, respectively, L_3 and L_5 levels. Solutions for logistics flows and elements are selected in a limited range of continuous values. For an approximate choice of such solutions, it is rational to use the methods of the theory of restrictions based on the sequential identification and elimination of bottlenecks [2]. The use of genetic algorithms gives a more accurate result [23]. In logistics systems of complex structure, changes in one element lead to changes in interconnected elements. Therefore, it is rational to choose solutions at the L_4 and L_6 levels for such systems using a combination of simulation and optimization models.

The implementation of optimization solutions to change the structure of the LS and the parameters of its elements requires adjustment of several resource flows an increase in the volume of financial flows. Changing the parameters of logistic elements and/or the structure of the LS to promote optimized logistic flows requires appropriate changes to the simulation model of the LS. These changes, in turn, can affect the parameters of logistics flows. The developed algorithm for implementing the multi-criteria model of IL (Figure 2) provides for iterative optimization of logistics flows and the LS until the maximum change in any of the parameters becomes less than a given value.

The sensitivity analysis of the developed multicriteria model is proposed to be performed using the simulation method. In the process of simulation modeling of the functioning of the logistics system of

the selected structure, the parameters of logistics flows are assessed, as well as the degree to which sustainable development goals are achieved.

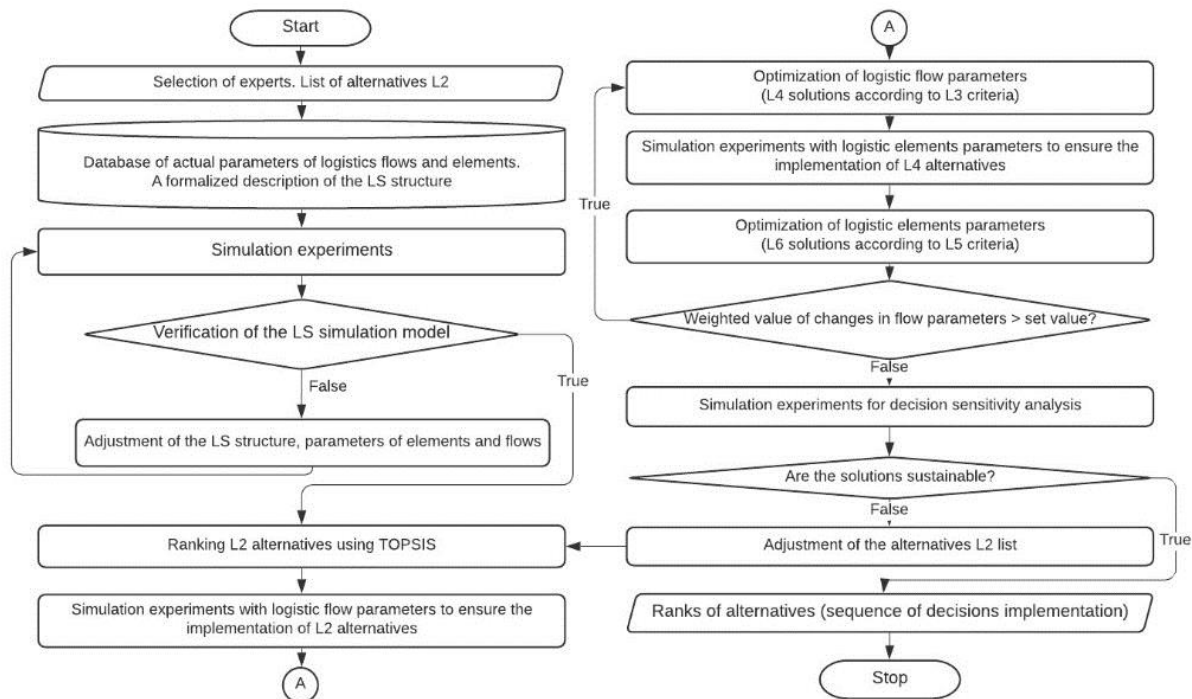


Figure 2. Flowchart of a multi-criteria model for the development of industrial logistics.

4. Conclusion

A new approach and model are designed for sustainable development of industrial logistics. The novelty of the approach is to combine the goals of sustainable development with the criteria of economic efficiency of an IL system. A feature of the developed multi-criteria model of IL is the combination of the multi attribute decision making TOPSIS method, MODM methods based on the use of genetic algorithms with a simulation model. It is proposed to use the TOPSIS method for ranking decisions to achieve the goals of sustainable development of IL. Genetic algorithms are used to optimize the parameters of logistics flows and elements of the logistics system. Such optimization ensures the implementation of sustainable development solutions. Finally, the simulation model is used as a means of obtaining input data for optimizing the parameters of logistic flows and elements, as well as for analyzing the sensitivity of the multicriteria model and the obtained solutions. An algorithm for implementing the proposed multicriteria model is developed. This algorithm determines the method and order of combining fuzzy MADM, MODM methods with each other and with a simulation model. The novelty of the research is also made up of the hierarchical system of criteria for sustainable development of the logistics system of an industrial enterprise and the proposed group of alternatives to achieve these criteria. A universal set of agents of the simulation model is proposed, which allows creating simulation models of production logistics systems of various industrial enterprises. Designed multi-criteria model will allow making informed decisions for the sustainable development of IL at all levels of enterprise management. Future research involves experiments using the developed multi-criteria model in a real industrial enterprise.

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